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TRANSMISSIVITY OF THE ATMOSPHERE FOR THERMAL RADIATION FROM NUCLEAR WEAPONS

by

M. G. Gibbons

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

SAN FRANCISCO · CALIFORNIA · 94135

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ABSTRACT

The transmissivity of the atmosphere is estimated for thermal radiation from a nuclear weapon of any given yield and height of burst under various atmospheric conditions. Situations in which the effective source height (for thermal radiation) is less than one-quarter mile*, the atmosphere is unclouded and the surface of the earth (or its covering) is of low albedo are considered first. The transmissivity for these situations is given in terms of a formula derived from earlier experiments of the author. Situations in which the effective source height (for thermal radiation) is equal to or greater than one-quarter mile are then considered, and basic transmissivity values are given in terms of effective fireball height and zenith angle for the case of an unclouded atmosphere, a visibility of about 12 miles and a low surface albedo. Factors are then given for modifying the basic transmissivity values to apply to other situations, such as ones with cloud cover or haze, and for taking into account high surface albedo. The factors for taking account of a cloud layer above the fireball and/or a high surface albedo are found to apply also to situations in which the effective fireball height is less than one-quarter mile.

*The "miles" used in this report are statute miles.

SUMMARY PAGE

The Problem:

Assessment of the thermal and fire effects of a given nuclear weapon burst on a given target requires a knowledge of the amounts of thermal radiation delivered from the nuclear weapon fireball to various portions of the target. This in turn requires a knowledge of the transmissivity of the atmosphere for fireball thermal radiation.

Findings:

The transmissivity of the atmosphere is estimated for thermal radiation from a nuclear weapon burst of any yield and height and for an inclusive list of sets of atmospheric and surface-albedo conditions. Directions are given for choosing the one of these sets of atmospheric and surface-albedo conditions that most nearly corresponds to any actually specified set of such conditions.

For nuclear weapon bursts with effective fireball heights (for thermal radiation) of less than one-quarter mile* the transmissivity of the atmosphere for the weapon thermal radiation is given in terms of a formula involving visibility and based on experiments carried out by the present author.

For nuclear weapon bursts with effective source heights (for thermal radiation) greater than or equal to one-quarter mile and an atmosphere that is free of clouds and characterized by a surface visibility of 12 miles, it is shown, by means of phenomenological arguments and checks against experimental results, that the transmissivity of the atmosphere for the weapon thermal radiation may be found (for a given burst-target geometry) by a calculation which assumes the radiation to behave as though it were all 0.65-μ radiation passing through an atmosphere everywhere two thirds as dense (optically) as Elterman's[1] "clear standard atmosphere" and were attenuated by "scattering out" only (without "buildup" or "scattering in"). Factors

*The "miles" used in this report are statute miles.

are then given for modifying the values calculated for this special atmosphere to correspond to other situations, such as atmospheres containing cloud cover or haze (factors of from 0.1 to 1.5), and for taking into account high surface albedo (factor of 1.5). The factors for taking account of a cloud layer above the fireball (factor of 1.5) or a high surface albedo (factor of 1.5) or both (factor of 2.25) are found to apply also to situations in which the effective fireball height is less than one-quarter mile.

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SECTION 1

INTRODUCTION

1.1 PURPOSE OF THIS REPORT

The purpose of this report is to present a straightforward, credible and readily usable method of calculating the transmissivity of the atmosphere for thermal radiation from a nuclear weapon burst. Transmissivity for a given fireball-receiver situation is here defined as the ratio of (1) the amount of fireball thermal radiation transmitted to the receiver under the actual atmospheric conditions to (2) the amount that would be transmitted to the receiver if only "inverse-square" attenuation occurred.

1.2 SCOPE

The method of calculation presented in this report is intended to be applicable to a nuclear weapon burst of any given yield at any given height above the earth's surface under any given atmospheric conditions and a receiver with a flat surface facing the burst point. (Such a receiver is approximately optimally oriented for reception of the thermal radiation from the weapon fireball.*) In order to allow the method to be usable in realistic planning situations, the input information used in the calculations is limited to the standard descriptive and quantitative information (e.g., cloud types, cloud base heights, surface visibility) that is ordinarily recorded at airport weather bureau stations.

*The albedo of the earth's surface (or its covering) is assumed to be either small (~0.15) or large (~0.75). If the albedo of the earth's surface (or its covering) were zero and no cloud cover were present, the receiver mentioned would be almost exactly optimally oriented.

1.3 APPROACH

The report proper begins by considering (in Section 2) nuclear weapon bursts for which the effective height of the source of thermal radiation is less than one-quarter mile* above the surface of the earth. For such bursts a method of calculating transmissivity is presented in terms of a formula previously derived by the author on the basis of experimental results. The formula involves the surface visibility, and in this connection some necessary comments are made on the meaning of visibility.

The report then considers (in Section 3) nuclear weapon bursts for which the effective height of the source of thermal radiation is one-quarter mile or more. For these bursts a method of calculating transmissivity is presented for the case of a special type of fairly clear atmosphere and a low surface albedo.

Factors are then given (in Section 4) for modifying the transmissivity corresponding to the just-mentioned case to take account of the effect of adding haze components, cloud layers and high surface albedo--in any combination. The factor to take account of a cloud layer above the fireball and the factor to take account of a high surface albedo are to be applied independently of the height of the fireball. The other factors are to be applied only to fireballs whose effective height for thermal radiation is one-quarter mile or greater.

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*The "miles" used in this report are statute miles.

SECTION 2

TRANSMISSIVITY OF THE ATMOSPHERE FOR THERMAL RADIATION FROM A NUCLEAR WEAPON FIREBALL AT AN EFFECTIVE HEIGHT OF LESS THAN ONE-QUARTER MILE (UNCLOUDED ATMOSPHERE AND LOW SURFACE ALBEDO)

2.1 REASON FOR THE CHOICE OF THE ONE-QUARTER MILE LIMIT

For an unclouded atmosphere of the usual type, that is, one containing a haze or smog component in addition to the atmospheric gases and water vapor, it can be shown that at altitudes* below about two miles the attenuation (other than "inverse-square" attenuation) of thermal radiation from nuclear weapons (visible and near infrared radiation) is accomplished principally by scattering by suspended particles [1] and absorption by water vapor[2], with the two types of attenuation, though differently distributed with respect to wavelength**, being roughly proportional to each other (considering simply their effects in decreasing the net transmission of nuclear weapon thermal energy) over a wide range of water vapor concentrations and path lengths.** A special atmosphere of this type, namely, one in which the haze component is present but is small enough so that the atmosphere would normally be considered clear, has been defined by Elterman[1] as a "clear standard atmosphere". For such an atmosphere the aerosol number density (number of suspended particles per unit volume) at an altitude of 0.25 mile is about three fourths of what it is at surface ("sea") level.[1] For an unclouded atmosphere that is of a different clarity than the clear standard atmosphere the number density at an altitude of 0.25 mile will usually be a somewhat different fraction (than three fourths) of the aerosol

*Altitudes are measured with respect to "sea level". For simplicity, surface level will be assumed to be at sea level, that is, at zero altitude. Actually the surface level need only be at or below an altitude of about 1 mile for the transmission formula 1 given in the present Section (1) to be valid (for source and receiver locations within about 0.25 mile of surface level).

**See Section 2.

number density at surface ("sea") level.* But in general the atmosphere cannot be considered even roughly uniform throughout a thickness of much more than 0.25 mile, and we will take 0.25 mile as the altitude below which estimates of thermal-radiation transmissivity based on "surface" measurements of atmospheric parameters (such as visibility) will be approximately valid and at or above which such surface-based estimates will not be valid.

2.2 METHOD OF ESTIMATION OF THE TRANSMISSIVITY OF THE ATMOSPHERE FOR THERMAL RADIATION FROM A FIREBALL AT AN EFFECTIVE HEIGHT OF LESS THAN ONE-QUARTER MILE (UNCLOUDED ATMOSPHERE AND LOW SURFACE ALBEDO)

Experiments to measure the transmissivity of the atmosphere for visible and near infrared radiation have been carried out at near surface level in the San Francisco Bay area and at the Nevada Test Site, using a spherically symmetrical source of radiation and a receiver with a flat surface facing the source. On the basis of these experiments, relationships of the general form

$$T_c = \epsilon^{-\sigma S_T} (1 + k_1 \sigma S_T) \qquad (1)$$

and

$$\sigma V = K_1, \qquad (2)$$

where $T_c \equiv$ transmissivity (dimensionless)

$\sigma \equiv$ attenuation coefficient (miles $^{-1}$),

$S_T \equiv$ effective slant range for thermal radiation (miles),

$V \equiv$ visibility as commonly observed (cf. 2.3) (miles),

$k_1 \equiv$ constant which depends on the wavelength (dimensionless),

$K_1 \equiv$ constant which depends on the wavelength and the observer's interpretation of liminal contrast (cf. 2.3) (dimensionless),

*For any type of atmosphere the molecular number density (total number of gas molecules per unit volume, not including molecules of water vapor) at an altitude of 0.25 mile is about 96% of what it is at zero altitude (sea level)[3].

have been found to be approximately valid for wavelengths in the visible and near infrared regions (and not in a region of absorption by water vapor) under a wide range of weather conditions in the absence of off-ground clouds.[4, 5]

Equations 1 and 2 may be combined to yield

$$T_c = e^{-K_1 S_T/V}\ (1 + K_2 S_T/V) \tag{3}$$

where

$$K_2 \equiv k_1\ K_1. \tag{4}$$

Choices of $k_1 = 0.7$ and $K_1 = 2$ (cf. 2.3), whence (by Eq. 4) $K_2 = 1.4$, were found to give a good fit of Eq. 3 to the data points for a wavelength of 0.55 μ. Substitution of $K_1 = 2$ and $K_2 = 1.4$ into Eq. 3 yields

$$T_c = e^{-2S_T/V}\ (1.4\ S_T/V) \tag{5}$$

Equation 5, although derived from data taken at a single wavelength of 0.55 μ, also gives a reasonably good fit to weapons-thermal transmissivity data for surface bursts and above-surface but surface-intersecting bursts as observed at surface stations, provided that a suitable choice of effective thermal partition* is made for each of the two types of burst. In checking Eq. 5 against weapons-thermal transmissivity data, an effective thermal partition of 0.21 was assumed for surface bursts as observed at surface stations, a thermal partition of 0.33 was assumed for an air burst,[6] and an effective thermal partition of 0.27, midway between that for a surface burst and that for an air burst, was assumed for an above-surface but surface-intersecting burst as observed at surface stations. Accordingly, these values of the thermal partition should be used with Eq. 5 in the corresponding cases.

Note that since application of Eq. 5 is restricted to thermal sources for which $h_T < 0.25$ mile, Eq. 5 should not be applied for distances S_T greater than about 45 miles, which is** the distance to the horizon from a point of elevation 0.25 mile.

*Thermal partition ≡ fraction of weapon detonation energy emitted as thermal radiation. Effective thermal partition (with respect to a given target) ≡ fraction of weapon detonation energy that would be calculated as emitted as thermal radiation energy on the basis of (1) the radiant exposure received at the target corrected for (i.e., divided by) atmospheric transmissivity and (2) an assumption that the weapon detonation is a spherically symmetrical source of thermal radiation.

**Taking $\sqrt{3h/2}$, with h in ft, as the distance to the horizon in miles.[7]

It is recommended that for points distant from the burst point by at least several times the maximum fireball radius Eq. 5 be used for estimation of the transmissivity T_c of the unclouded atmosphere for thermal radiation reaching a given "observation point" (actually an area oriented to face the source of thermal radiation) on the surface from a nuclear weapon burst (whether a surface burst, an above-surface but surface-intersecting burst, or an air burst) at an effective height (for thermal radiation emission) of less than 0.25 mile.

For surface observation points distant from the burst point by at least several times the fireball radius,* the value of S_T may be taken, as an approximation on the basis of geometrical considerations, as that of the slant range S_B from the burst point minus 0.6 of the fireball radius (whether the burst is a surface burst, an above-surface but surface-intersecting burst, or an air burst). That is,

$$S_T = S_B - 0.6\,R, \qquad (6)$$

where

$S_T \equiv$ effective slant range for thermal radiation to given observation point P,

$S_B \equiv$ slant range from burst point to observation point P,

$R \equiv$ fireball radius $\equiv$ radius of non-flat portion of fireball surface at time of second thermal maximum, and S_T, S_B and R are all in miles.

In order to decide whether or not Eq. 5 is applicable to a given surface or very-low-altitude burst, one needs to know the effective (for thermal radiation**) height of the thermal source (fireball). Let us call this height h_T.

*Unless otherwise indicated, "fireball radius" $\equiv$ radius of the non-flat portion of the fireball surface at time of second thermal maximum. The "fireball radius" thus defined is about 4/5 of the maximum fireball radius and is considered to be the effective fireball radius for thermal radiation.

**Note that h_T, the effective height of the fireball for thermal radiation, ought not to be called an effective height "of burst" for thermal radiation, since it will not in general be the same as the effective height of the weapon considered as a source of blast. The latter effective height is conventionally taken as identical with with the actual height of burst.

For an air burst and surface observation points distant by at least several fireball radii from the burst point the value of h_T may be assumed approximately equal to that of the height of burst h, while for a surface burst (and for observation points as mentioned) h_T may be taken, as an approximation on the basis of geometrical considerations, as 0.4 of the fireball radius.

For an above-surface but surface-intersecting burst (i.e., fireball), that is, one which is neither close enough to the surface to be classed for practical purposes as a surface burst nor far enough off the surface to be classed for practical purposes as an air burst, h_T may be taken (for observation points as mentioned) as approximately 0.7 (i.e., midway between 1.0 and 0.4) of the fireball radius.

Thus, we will make use of the following relationships:

$$h_T \text{ (air burst)} = h, \tag{7}$$

$$h_T \text{ (above-surface but surface-intersecting burst)} = 0.7\ R, \tag{8}$$

$$h_T \text{ (surface burst)} = 0.4\ R, \tag{9}$$

where h_T and R have been defined above, h = height of burst, and h_T, R and h are all in miles.

In calculating the fireball radius R for a given type of fireball (from bursts at altitudes of less than about 30 miles), one may use the appropriate one of the following approximate relationships:[8]

$$R \text{ (air burst)} = 0.41\ W^{0.35} e^{0.0465h}, \tag{10}$$

$$R \text{ (above-surface but surface-intersecting burst)} = 0.47\ W^{0.35}\ e^{0.0465h}, \tag{11}$$

$$R \text{ (surface burst)} = 0.53\ W^{0.35} e^{0.0465h}, \tag{12}$$

where R is in miles, W is the weapon yield in MT, and h is the altitude in miles of the burst point above sea level.*

*Note that the applicability of Eqs. 10, 11 and 12 includes but is not restricted to situations in which surface level is at sea level.

Eq. 10 includes the assumptions that R is proportional to $(\rho/\rho_0)^{-0.2}$, where ρ and ρ_0 are the air densities at altitude and at sea level, respectively, and that[7]

$$\rho = \rho_0 e^{-h/4.3}. \tag{13}$$

Eq. 12 is derived from Eq. 10 on the assumption that for a given yield the volume of the (hemispherical) fireball of a surface burst is equal to the (spherical) volume of the fireball of an air burst. The initial coefficient in Eq. 11 was chosen to give a result midway between the results of Eqs. 10 and 12 for given values of W and h.

On the basis of Eqs. 7 through 12 it can be shown that the limitation of the use of Eq. 5 to paths lying below h_T = 0.25 mile means that Eq. 5 cannot be applied to nuclear weapon bursts of yields greater than 0.24 MT in the case of an airburst, 0.45 MT* in the case of a typical above-surface but surface-intersecting burst, and 1.61 MT in the case of a surface burst.

In using Eq. 5 to estimate thermal irradiances in cases where the visibility is not known, the following table[10] of correlations between atmospheric conditions and visibility may be used.**

Table 1

Approximate Visibilities Corresponding to Various Atmospheric Conditions

Atmospheric condition	Approximate visibility (miles)
Very clear	30
Clear	12
Light haze	6
Haze	2.5

*The value of 0.45 MT corresponds to an above-surface but surface-intersecting burst for which the fireball radius (chosen on the basis of Eq. 8) is about 0.36 mile.

**See also 4.1

2.3 NOTES CONCERNING THE MEANING OF VISIBILITY

The "visibility" for a given locality is an estimate of the "visual range" for that locality, that is, an estimate of the distance at which an object "of reasonable size" can be distinguished from its background (that is, will have "liminal contrast" with its background) in daylight.[11] In practice such an estimate is made by deciding which one of a number of objects located at known distances from the observer is the most distant one that can be seen fairly clearly. Similar estimates made at night using lights located at known distances from the observer are also, by extension of the concept, called "visibilities".

The term "meteorological range" is more clearly defined[12] than visibility and has sometimes been (incorrectly) used interchangeably with visibility. On the basis of limited evidence[13] the present author concludes that the visibility as commonly observed (e.g., at airport weather stations) is about one-half the meteorological range. (In special experiments conducted specifically to compare visibility with meteorological range, the visibility was found to be about three fourths of the meteorological range.[14]) Thus if we define σ = attenuation coefficient (miles^{-1}), R_m = meteorological range (miles), and V = visibility as commonly observed (miles), we have[15]

$$\sigma R_m = 3.912 \tag{14}$$

and[13]

$$\sigma V \cong 2. \tag{15}$$

The result reported for the visibility in a given situation will depend not only on the scattering and absorbing properties of the atmosphere, but also on the angular subtense of the object (from the location of the observer), the color of the object, the background luminance, and the observer's interpretation of liminal contrast. For an estimate made in daylight and based on observation of a number of very dark objects (that is, objects with intrinsic luminance of close to zero[15]) against the horizon sky, the result will not depend appreciably on the absorbing properties of the atmosphere nor on the position of the sun.[15]

Because of the rather ill-defined nature of visibility, formula 5 should be treated as purely empirical. No attempt will be made to derive this formula from elementary considerations, except to state that is is of a form that would be expected on the basis of attenuation by scattering alone, that is, an exponential attenuation factor multiplied by a "buildup" factor. To the present author this indicates that for a wide range of water vapor concentrations and path lengths and for the sum of the visible and near-infrared energy emitted by a nuclear-weapon explosion the energy attenuation due to scattering is roughly proportional to the energy attenuation due to water vapor absorption. For a given number of condensation nuclei one would, in general, expect more water droplets (scattering particles) for a higher concentration of water vapor (absorbing material).* It is certainly not true (though it is often stated to be so) that for a wide range of water vapor concentrations practically all of the weapon thermal energy in the wavelength subregion where absorption by water vapor occurs will be absorbed in the first few miles of path.[16]**

*More specifically, one would expect (the concentration of droplets for a given concentration of condensation nuclei and hence) the attenuation coefficient for scattering to be a monotonic increasing function of the relative humidity, while the attenuation coefficient for absorption is in general a monotonic increasing function of the absolute humidity. Also, the scattering attenuation removes energy primarily from the "blue" end of the energy region in question, while the absorption attenuation removes energy from the "red" end (namely, from the regions of the H_2O absorption bands).

**This reference shows the true situation.

SECTION 3

TRANSMISSIVITY OF THE ATMOSPHERE FOR THERMAL RADIATION FROM A NUCLEAR WEAPON FIREBALL AT AN EFFECTIVE HEIGHT OF ONE-QUARTER MILE OR HIGHER (UNCLOUDED ATMOSPHERE AND LOW SURFACE ALBEDO)

3.1 DEFINITION OF THE ATTENUATION MODEL

A model of a "clear standard atmosphere", that is, an atmosphere which, though containing a haze component, is normally spoken of as "clear", has been developed by Elterman (cf. 2.1), who gives[1] optical thicknesses based on this model for vertical paths from surface level (more precisely, from sea level) to altitudes of from 1 to 50 km (by 1-km. intervals) and for each of twenty-two wavelengths in the 0.27 to 4.0-μ region of the spectrum. The optical thicknesses given by Elterman take into account absorption by ozone. However, the infrared wavelengths chosen are outside of the absorption bands of the infrared absorbing vapors and gases present in the atmosphere.* Thus, except for taking into account absorption by ozone, the optical thicknesses given by Elterman for the visible and near infrared regions (the significant regions of the thermal radiation output spectrum of a nuclear weapon as far as near-sea-level receivers are concerned) are based on scattering only, in fact, on "scattering out" only (neglecting "buildup" or "scattering in"), and do not take absorption into account. On the basis of the fact that the scattering-only transmissivity --- taking into account scattering out and also buildup or scattering in --- for 0.55 μ was found (cf. 2.2) to be approximately equal to the overall transmissivity for the thermal radiation effectively emitted** by a nuclear weapon fireball at an effective height (for thermal radiation) of less than 0.25 mile and the fact that the attenuation coefficient

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*The most important of these is H_2O. The second most important is CO_2. Of considerably less importance are N_2O, CH_4 and CO.

**That is, reaching points beyond the immediate vicinity of the fireball. 17

for scattering (i.e., scattering out) decreases with increasing wavelength,* one may surmise that the scattering-out transmissivity for a somewhat higher wavelength than 0.55 μ might also give a reasonably good fit to the overall transmissivity. A check shows that this appears in fact to be the case. The check is made for a situation of low surface albedo and an atmosphere which is cloudless and characterized by a surface visibility of 12 miles, and is based on the use of two thirds of the "extinction" optical thicknesses as given by Elterman[1] for 0.65 μ.

The optical thicknesses given in ref. 1 are there stated to be for a "meteorological range of about 25 km" (~16 miles) "at sea level". Hence they should be valid for an 8-mile visibility (cf. 2.3). To get the corresponding overall optical thicknesses τ for a 12-mile visibility, we take two thirds of the "extinction" optical thicknesses given in ref. 1. This procedure is carried out on the basis of the assumption that for a given burst-receiver geometry and for the range of visibilities (8-12 miles) in question

$$\tau V \cong \text{constant}, \tag{16}$$

where τ is the optical thickness (dimensionless) for the slant path involved and V is the visibility (miles). (Eq. 16 may be regarded as a generalization of Eq. 15.) Actually, changes in visibility in an atmosphere which does not contain fog are primarily due to changes in the Mie-particle component of the atmosphere (or the "aerosol" component, to use the nomenclature of Elterman[1]). However, it is more convenient, and not appreciably different in result, simply to apply a factor of two thirds to the sum of the components.** Thus, let us suppose that one takes two thirds of the "extinction" optical thicknesses as given by Elterman for 0.65 μ and, neglecting buildup, calculates transmissivity for any given slant path. When this is done for a wide range of source altitudes and slant-path lengths, it is found that the variation of the calculated transmissivity

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*For example, letting σ_c be the attenuation coefficient for scattering and λ the wavelength, we have $\sigma_c \propto \lambda^{-4}$ for Rayleigh scattering and $\sigma_c \propto \lambda^{-0.7}$ for scattering by an ordinary haze.[18]

**It can readily be shown that Elterman's treatment implies that the "extinction" optical thickness for a given wavelength and slant path is equal to the sum of the Raleigh, "ozone" and "aerosol" optical thicknesses for that wavelength and path.

with source altitude and slant-path length is qualitatively as expected and that, as will be shown below, for source altitudes of 20 miles or more the calculated transmissivities correlate appropriately with those for luminous solar radiation and a clear atmosphere, while for a source altitude of 0.25 mile the calculated transmissivities correlate appropriately with those calculated from Eq. 5 (valid for nuclear weapon thermal radiation and for source altitudes below 0.25 mile) on the basis of a 12-mile visibility.

For in-atmosphere bursts in the megaton range* a wavelength of 0.65μ appears to be close to the average value of the wavelength at which (per unit wavelength interval) the maximum amount of thermal energy is emitted (more precisely, measured). It should be noted, however, that 0.65 μ is not the wavelength above and below which equal amounts of thermal energy are emitted (more precisely, measured). The latter wavelength is in fact approximately 0.8 μ. However, the atmospheric attenuation of 0.8-μ radiation, a weak attenuation by scattering only, cannot be taken as even roughly characteristic of the atmospheric attenuation of the weapon thermal radiation, since the band of weapon thermal radiation of wavelength shorter than 0.8 μ is, considered as a whole, fairly strongly attenuated by scattering and the band of weapon thermal radiation of wavelength longer than 0.8 μ is, considered as a whole, fairly strongly attenuated by absorption. But the atmospheric attenuation of 0.65-μ radiation, a fairly strong attenuation by scattering, can be taken as roughly characteristic of the atmospheric attenuation of the weapon thermal radiation, as the arguments presented above have shown.

3.2 APPLICATION OF THE ATTENUATION MODEL

For low surface albedo and an atmosphere which is cloudless and characterized by a surface visibility of 12 miles, transmissivities for thermal radiation from in-atmosphere nuclear bursts, based on two thirds of Elterman's results for 0.65-μ radiation, are given in Fig. 1 for various effective (for thermal radiation) slant paths as a function of sec $\theta_T \equiv S_T/h_T$, where θ_T is the effective zenith angle (for thermal radiation) of the fireball (i.e., θ_T is the angle between the effective slant path and the vertical), S_T is the effective slant range for thermal radiation,** (with h_T in the same units as S_T). In particular, transmissivities T_c are plotted in Fig. 1 as a function

*The same statement appears to be true also for in-atmosphere bursts in the kiloton range.[17]

**For equations giving S_T and h_T in terms of more commonly used parameters, see Section 2.

of sec θ_T for h_T = 0.25, 0.35, 0.5, 0.7, 1, 1.5, 2, 3, 5, 10, and 20 miles. The equations used in plotting the curves in Fig. 1 are of the form

$$T_c = e^{-\tau(h_T)\sec\theta_T}, \tag{17}$$

where $\tau(h_T)$ is the optical thickness for radiation of wavelength 0.65 μ of a vertical path from the surface level (assumed to be at sea level) to altitude h_T. The values of $\tau(h_T)$ corresponding to the values of h_T listed above were found by graphical interpolation in Fig. 2, which is a plot of column 1 (in miles) and two-thirds* of column 8 of Table 5.13 of ref. 1, and are given in Table 2.

Table 2

Optical Thickness $\tau(h_T)$ (Dimensionless) for a Vertical Path From Altitude h_T (Miles) to Sea Level

h_T (miles)	$\tau(h_T)$
0.25	0.0310
0.35	0.0443
0.5	0.0603
0.7	0.0777
1.0	0.0952
1.5	0.1130
2	0.1239
3	0.1341
5	0.1426
10	0.1531
20	0.1662
30	0.1680
(∞	0.1680)[a]

[a]Based on column 9 of Table 5.13 of ref. 1.

*See fourth footnote to 3.1

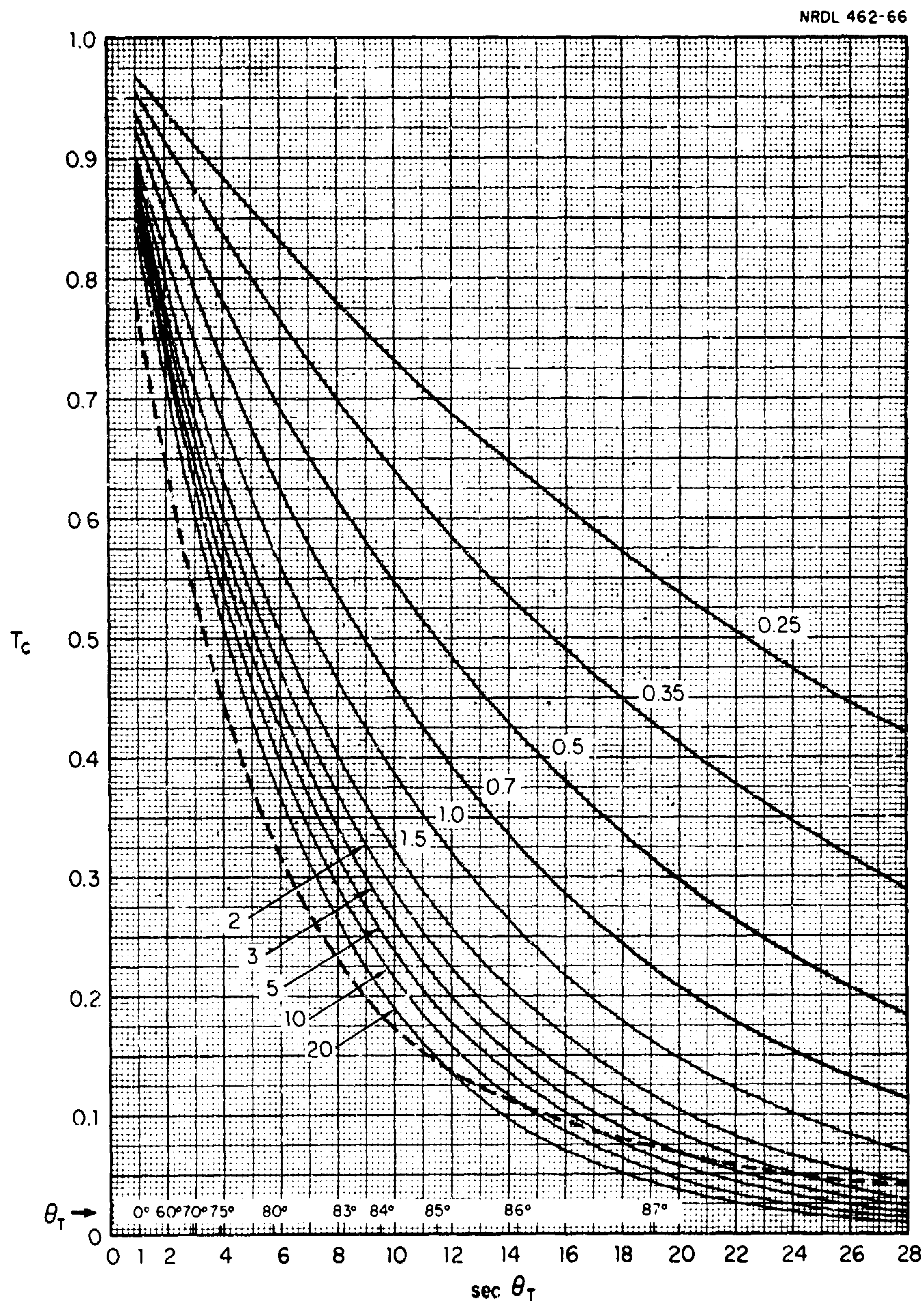

Fig. 1 Transmissivity T_c as Given by Eq. 17 versus sec θ_T ($\approx \varepsilon_T/h_T$) for Various Values of h_T (Solid Curves) Compared With Atmospheric Transmissivity for Solar Luminous Energy versus sec θ_T (Dashed Curve). The Number Adjacent to Each Solid Curve Gives the Corresponding Value of h_T (Miles).

It is evident from Fig. 1 that (as would be expected) the transmissivity T_c (as given by Eq. 17 and either Fig. 2 or Table 2) decreases for a given θ_T as h_T increases. From the last three pairs of entries in Table 2, it is evident that the decrease in T_c (for given θ_T) as h_T increases from 20 miles to 30 miles is small compared to the value of T_c for h_T = 20 miles and that the decrease in T_c as h_T increases from 30 miles to infinity is (to within the accuracy of Fig. 2 and Table 2) zero. Thus the curve (or the corresponding analytical expression, of the form of Eq. 17 and with $\tau(h_T) = 0.1662$) for h_T = 20 miles may be used for estimating T_c (for given θ_T) for $h_T \geq$ 20 miles*. For $h_T >$ 20 miles this will give a slightly conservative, i.e., high, result for T_c. Similarly the 10-mile curve may be used for 20 miles $> h_T \geq$ 10 miles, the 5-mile curve for 10 miles $> h_T \geq$ 5 miles, the 3-mile curve for 5 miles $> h_t \geq$ 3 miles, the 2-mile curve for 3 miles $> h_T \geq$ 2 miles, the 1.5-mile curve for 2.0 miles $> h_T \geq$ 1.5 mile, the 1.0-mile curve for 1.5 mile $> h_T \geq$ 1.0 mile, the 0.7-mile curve for 1 mile $> h_T \geq$ 0.7 mile, the 0.5-mile curve for 0.7 mile $> h_T \geq$ 0.5 mile, the 0.35-mile curve for 0.5 mile $> h_T \geq$ 0.35 mile, and the 0.25-mile curve for 0.35 mile $> h_T \geq$ 0.25 mile. In any given case the corresponding analytical expression, of the form of Eq. 17 and with $\tau(h_T)$ as given in Table 2, can, of course, be used instead of the indicated curve. Again, if for given values of h_T and S_T a better approximation to T_c or $\tau(h_T)$ is desired than that given by use of a specific curve of Fig. 1 or a specific value of $\tau(h_T)$ from Table 2, interpolation in Fig. 1 or Table 2, or in Fig. 2, which is a "plot" of Table 2, may be used.

Comparison of the 20-mile curve with a transmission curve for direct plus diffuse solar luminous radiation (0.42 to 0.7 μ, with peak at 0.556 μ) given by Passell[19] and reproduced (dashed curve) in Fig. 1 shows that the transmissivity of the atmosphere for direct plus diffuse solar luminous radiation (peak at 0.556 μ) is not much different from the transmissivity of the atmosphere for direct plus diffuse thermal radiation from a nuclear weapon fireball (peak at ~ 0.65 μ) at $h_T \geq$ 20 miles. The solar radiation, being of shorter average wavelength than the fireball radiation, undergoes more <u>scattering out</u> than does the fireball radiation. However, the difference in <u>scattering out</u> is to a great extent made up for (or, in the case of zenith angles greater than about 86 degrees, more than made up for, as may be seen from Fig. 1) by the additional <u>scattering in</u> of the solar radiation that results from its illuminating a larger portion of the atmosphere than does the fireball radiation.

*A curve for h_T = 30 miles (which would be the same as the curve for $h_T = \infty$) would, if drawn on Fig. 1, be so close to the curve for h_T = 20 miles as to be indistinguishable from it.

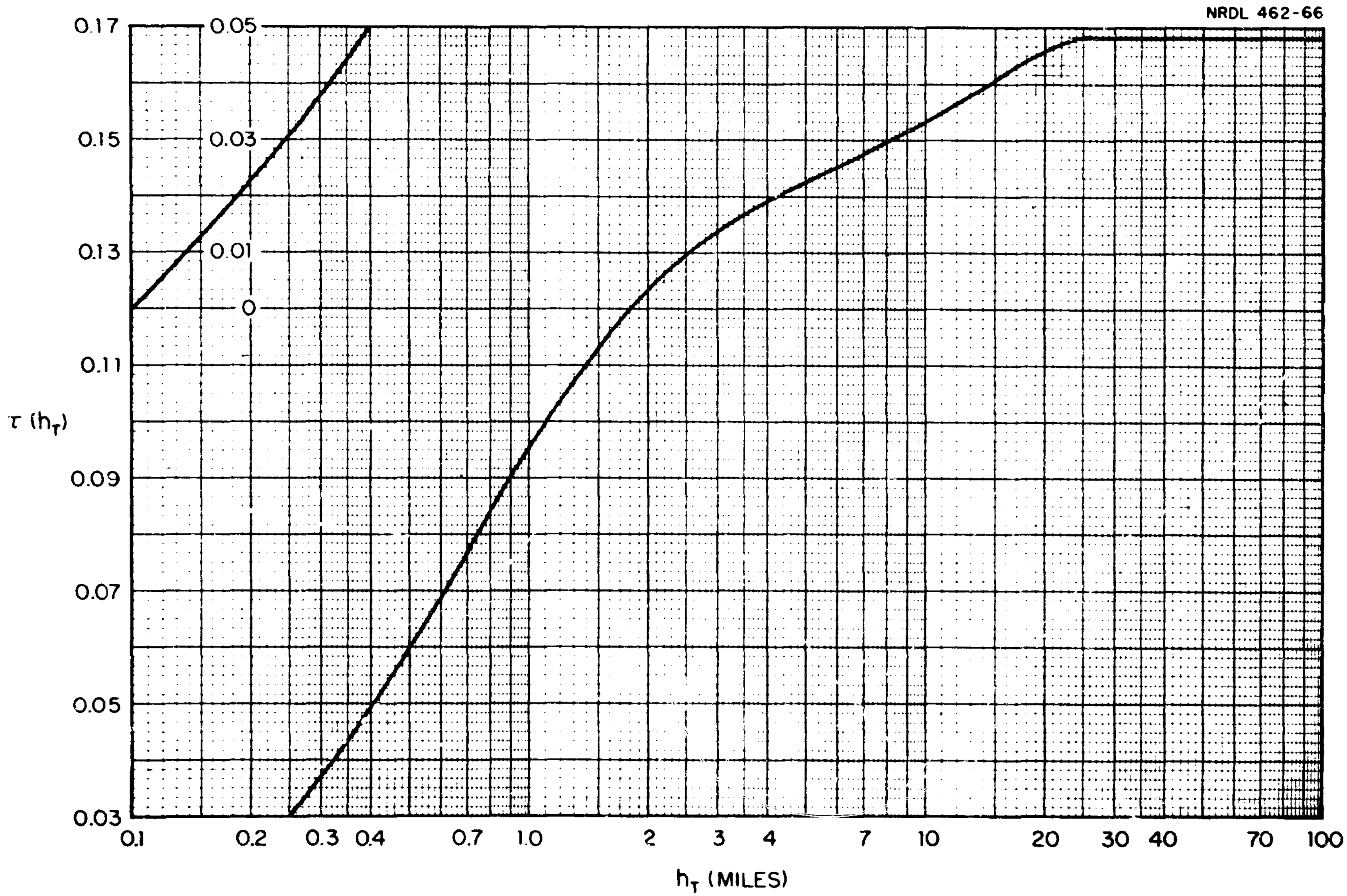

Fig. 2 Optical Thickness $\tau(h_T)$ as a Function of h_T.

As was pointed out in 2.2, for nuclear weapon bursts having $h_T < 0.25$ mile Eq. 5 should be used. To allow comparison of the results obtained by using Eq. 5 with the results obtained by using the 0.25-mile curve of Fig. 1 (or the corresponding analytical expression $T_c = e^{-0.0310 \sec \theta_T}$, or inserting S_T (miles)/0.25 (mile) for $\sec \theta_T$, $T_c = e^{-0.1240 S_T}$), the 0.25-mile curve of Fig. 1 is replotted (and extended) in Fig. 3 as a T_c vs S_T curve along with the T_c vs S_T curve corresponding to Eq. 5 for V = 12 miles. It is evident from Fig. 3 that the two curves are in rough agreement and that for S_T less than about 41 miles (which covers almost the entire range of applicability of Eq. 5 -- cf. 2.2) the result given by Eq. 5 (for V = 12 miles) is somewhat greater than that given by the 0.25-mile curve, while for S_T greater than about 41 miles the result given by Eq. 5 is somewhat smaller than that given by the 0.25-mile curve.

3.3 ATTENUATION FOR A VISIBILITY OTHER THAN THAT OF THE MODEL

For the case of low surface albedo and a nuclear weapon burst having $h_T \geq 0.25$ mile an estimate of the effect on τ of a visibility V different from 12 miles may be obtained by means of expedients which will now be presented.

For V greater than 12 miles but not more than 20 miles, it is recommended that Eq. 16 be assumed valid and that, accordingly, the τ values of Table 2 be modified by a factor 12/V (with V in miles). The same procedure should be used for V less than 12 miles but not less than 8 miles (Cf. 3.1).

For V greater than 20 miles it is recommended that the τ values corresponding to V = 20 miles be used, since visibilities greater than about 20 miles would normally be recorded with the observer and/or the observed object at a considerably greater elevation than the average elevation of the intervening terrain and hence should probably not be regarded as true "surface" visibilities.

Situations in which V is less than 8 miles will ordinarily be accompanied by light or heavy haze or fog. Transmissivities for these situations (and for other situations not yet treated in the present report) are treated in Section 4.

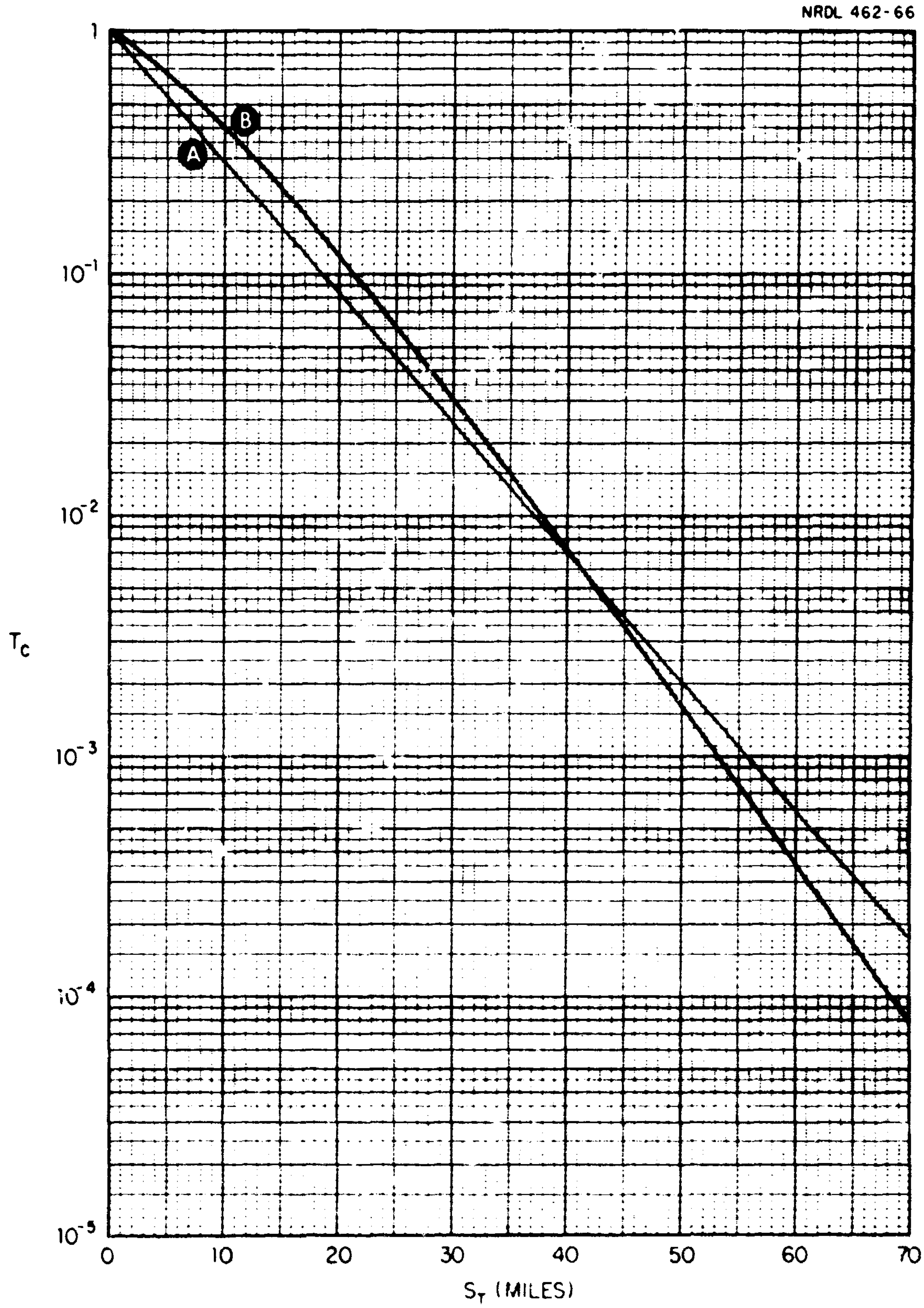

Fig. 3 Comparison of the 0.25-Mile Curve of Fig. 1 Replotted as a T_c *versus* S_T Curve (Curve A) With the T_c *versus* S_T Curve Given by Eq. 5 for V=12 Miles (Curve B).

SECTION 4

THERMAL TRANSMISSIVITY FOR A CLOUDED ATMOSPHERE AND OTHER SPECIAL CASES

4.1 FACTORS FOR TAKING ACCOUNT OF A SINGLE CLOUD OR HAZE LAYER WHEN THE EFFECTIVE HEIGHT OF THE FIREBALL IS ONE-QUARTER MILE OR MORE (LOW SURFACE ALBEDO)

In calculating thermal input (radiant exposure) at a point* having a single layer of clouds between it and the effective origin of the thermal radiation (assumed here to be at a height of one-quarter mile or more), an appropriate factor, which we will call T', should be multiplied by the clear atmosphere transmissivity T_c, as obtained from Eq. 17, to give the overall transmissivity T ($T = T_c T'$).

Use of the formulation $T = T_c T'$ implies the assumption that the cloud or haze layer does not replace any considerable portion of the atmosphere for which T_c has been calculated, that is, any portion contributing a considerable part of that atmosphere's optical thickness. This assumption is correct to a first approximation. It is evident, however, that for a cloud or haze layer of given composition and altitude the approximation is better if that cloud or haze layer is of small vertical extent than if it is of large vertical extent. It is evident also (cf. Fig. 2) that the approximation is better for a given cloud or haze layer at high altitude than for the same cloud or haze layer at low altitude.

The transmission of a cloud or haze layer depends on the density of the cloud or haze layer and on the particle size. The nature of the dependence has been studied theoretically for clouds by Hewson.[20] However, it is more useful in the present application to establish relationships between cloud- or haze-layer transmission and cloud or haze type, or between cloud- or haze-layer transmission and the appearance of the cloud or haze layer (or of the sun and sky with the cloud or haze layer present) to an observer at the surface of the

*Actually a receiver with face normal to a line from it to the effective thermal source. Also, a situation of low surface albedo is considered, unless otherwise mentioned. (High-surface-albedo situations are considered below.)

earth, than between cloud- or haze-layer transmission and cloud or haze density and particle size, since it is cloud or haze type or cloud or haze appearance, not cloud or haze density and particle size, that is usually observed.* The relationship between cloud-layer transmission and cloud type was studied experimentally by Haurwitz,[21] and the relationship between cloud- and haze-layer transmission and cloud- and haze-layer appearance was studied experimentally by Jones and Condit.[22] The results obtained by these (three) investigators may be used as the basis for a choice of values of T' corresponding to various types of clouds and hazes. Values of T' chosen on such a basis and appropriate for use with zenith angles near 60° are given in Table 3. A correction factor for use with zenith angles not near 60° is given below.

Table 3

Factors T' by Which the Transmissivity Is Reduced When a Single Cloud or Haze Layer Is Between the Fireball and the Observation Point (Zenith Angle Near 60°)

Type of Cloud or Haze Layer[a]	T' ($\theta \sim 60^\circ$)
Light haze (sky white, almost dazzling near sun)	0.7
Medium haze (sky bright gray-white)	0.5
Heavy haze (sky dull gray-white)	0.4
Light cloud (sky light gray)	0.3
Medium cloud (sky dull gray)	0.2
Heavy cloud (sky dark gray)	0.1

[a] As visually observed with the sun at a zenith angle of about 60°. The restriction on the sun's zenith angle at the time of observation is imposed in order to allow correlation of a given observed (sun and) sky appearance with a definite set of atmospheric conditions. (See below.) For more complete descriptions of the appearance of the (sun and) sky for each cloud and haze type, see ref. 22. For no cloud or haze layer present, T' = 1.

The values of T' given in Table 3 are actually taken from Fig. 5 of ref. 19 and are based on (and referenced to) the work of Jones and Condit.[22] The assignment of an effective zenith angle of 60° to them is made (by the present author) on the basis of a comparison of (1)

* Cf. ref. 21.

data taken by Haurwitz[21] on transmission of high, middle and low clouds* for a horizontal (upward-facing) receiver and adjusted by Passell to correspond to a receiver facing the source** with (2) values of the transmission*** of light, medium and heavy clouds as calculated from the ratio of the "luminous density" at sea level with the cloud present to the "luminous density" at sea level for a clear atmosphere[22] (cf. Table XIV of ref. 22 and Fig. 5 of ref. 19). The comparison shows that the transmission values for the high, middle and low clouds of Haurwitz[21] (as adjusted in the manner of Passell[19] to correspond to a receiver facing the source) for a zenith angle of 60° correspond respectively to the "luminous-density" transmission values for the light, medium and heavy clouds of Jones and Condit[22]****. For

---

* High clouds (height of base ranging from about 20,000 ft (6000 m) up[23]) for which data are given by Haurwitz[21] are cirrus and cirro-stratus. Middle clouds (height of base ranging from about 6500 ft (2000 m) to about 20,000 ft (6000 m)[23]) for which data are given by Haurwitz[21] are altocumulus and altostratus. Low clouds (base ranging from near the surface to a height of about 6500 ft (2000 m)[23]) for which data are given by Haurwitz[21] are stratocumulus, stratus, and nimbostratus. Ref. 21 (Haurwitz) does not give transmission data for cirrostratus (a type of high cloud), nor for clouds with "vertical development"[23] (cumulus, cumulonimbus and mammatocumulus).

** Passell[19] actually makes two adjustments. In one of them he does not include a correction factor to take account of the portion of the receiver field of view that is occupied by the earth and in the other he does include such a correction factor but also essentially assumes the albedo of the earth to be zero. An average of the two adjustments has been used in this work.

*** These are the values of T' given in Table 3 for the three types of cloud layers included there.

**** The latter transmission values are, by design, correlated directly with the appearance of the sun and sky. According to Jones and Condit[22] the appearance of the sun and sky for a given set of atmospheric conditions will usually be a function of solar zenith angle, as will the "luminous-density" transmission, but a given appearance of sun and sky will correspond to the same "luminous-density" transmission value regardless of the solar zenith angle. (Thus a given appearance of sun and sky corresponds to different sets of atmospheric conditions for different zenith angles.)

example, the T values 0.2 and 0.1 given in Table 3 for medium and heavy clouds and $\theta = 60^{\circ}$ may be seen to be, respectively, a rounded-off average of the four values (0.25, 0.17, 0.20 and 0.13) given in Table III of ref. 19 for $\theta = 60^{\circ}$ for the middle clouds altocumulus and altostratus and a rounded-off average of the six values (0.17, 0.11, 0.12, 0.08, 0.10 and 0.07) given in the same table for $\theta = 60^{\circ}$ for the low clouds stratocumulus, stratus and nimbostratus.

If any of the cloud or haze layers listed in Table 3 extends up from surface level, that cloud or haze layer will normally be associated with a fairly narrow range of visibilities. It is accordingly possible to make a rough assignment of surface visibility to the on-surface presence of each type of cloud or haze layer listed in Table 3, and thence to each corresponding value of T'. Specifically it may be assumed[8] that the visibilities, cloud or haze layer types, and values of T' are associated as in Table 4.

Table 4

Visibilities V Associated With a Single Cloud or Haze Layer Extending up From Surface Level, and the Corresponding Values of T' (Zenith Angle Near 60°)

Type of Cloud or Haze Layer Extending up From Surface Level	V (miles)	T' ($\theta \sim 60^\circ$)
Light haze	6	0.7
Medium haze	3	0.5
Heavy haze	2	0.4
Light cloud (thin fog)	1.2	0.3
Medium cloud (light fog)	0.6	0.2
Heady cloud (medium to thick fog)	0.5 mile or less	0.1

For visibilities of 8 miles or more (unclouded atmosphere, low surface albedo, and effective fireball height one-quarter mile or more) the overall transmissivity should not be calculated as $T = T_c T'$, but instead should be calculated in the manner indicated in 3.3.

For a nuclear weapon fireball at an effective height of less than one-quarter mile, the transmissivity T should also not be obtained as $T_c T'$. Instead the appropriate value of V should be used in Eq. 5, which will give the overall transmissivity directly. It should be noted, however, that while Eq. 5 has been verified for hazes on the surface, it has not been tested experimentally for clouds on the surface (or fogs).

As has already been indicated, the values T' given in Tables 3 and 4 correspond to actual values of transmission of nuclear weapon thermal radiation through the various haze or cloud types for elevation angles of about 30°, or zenith angles of about 60°. For a fireball above a cloud or haze layer, the degree of sphericity of the polar diagram representing the intensity and distribution of the scattered plus direct fireball-thermal radiation that emerges from any small area on the bottom of the layer will usually be less if the layer is a haze than if it is a cloud. (Cf. Fig. 22 of ref. 22.) However, for either type of layer (with the restriction in the case of light haze to a fireball not occupying a field of view of more than about 2°) the radiation received by an optimally oriented 180°-field-of-view receiver below the layer will be (all or) practically all scattered radiation. (Cf. Table XIII of ref. 22.) For any of the types of cloud or haze listed in Tables 3 and 4 and for a given value of zenith angle θ greater than 30° and less than about 80°, the value of T' as given in Tables 3 and 4 may be corrected by use of a factor $\cos\theta/\cos 60^{\circ}$. For $\theta \geq 80^{\circ}$ or $\theta \leq 30^{\circ}$ the correction factor for $\theta = 80^{\circ}$ or $\theta = 30^{\circ}$, respectively, should be used, since at zenith angles above 80° or below 30° a change in zenith angle (for cloud or haze thickness $\ll S_T$) would not be expected to be accompanied by an appreciable change in cloud or haze transmission. (Cf. Table III of ref. 19).

For a surface or near-surface fireball that is below a complete and sufficiently thick cloud cover a limited amount of data[13,21] indicates that the ratio of the amount of thermal energy delivered onto a flat target facing the fireball to the amount that would be delivered in the absence of clouds increases from 1 at very short slant ranges to about 2 at slant ranges which are equal to between about 5 and 12 times the height of the clouds above the surface.* For larger slant ranges this ratio decreases somewhat, but remains greater than unity.[13,24] For fireballs below a less complete or less thick cloud cover (or a complete cloud cover that is not complete in any single layer) the effect of the clouds in enhancing the transmissivity will not be so great.

Since for high-yield weapons important thermal effects can occur at ranges considerably greater than 12 times the height of the clouds above the surface, use of a compromise factor T' = 1.5 for all slant ranges for the fireball-below-complete-cloud-cover situation would seem to be reasonable, and this procedure is recommended. It should be used for effective fireball heights (for thermal radiation) equal to or greater than one-quarter mile as well as for those less than one-quarter mile (for which it was found experimentally).

4.2 FACTORS FOR TAKING ACCOUNT OF ANY NUMBER OF HAZE AND/OR CLOUD LAYERS TOGETHER WITH HIGH OR LOW SURFACE ALBEDO WHEN THE EFFECTIVE HEIGHT OF THE FIREBALL IS ONE-QUARTER MILE OR MORE

For practical purposes any given atmosphere-fireball configuration can be reduced (for a surface-level observation point) to one of the following four:

*Cloud albedo (for radiant energy with wavelength distribution corresponding approximately to that in question here) is in general a monotonic increasing function of cloud thickness and cloud density and can range from about 0 to about 0.8.[20] A combination of cloud thickness and density sufficient to give an albedo of about 0.5 or greater is assumed here. For coastal stratus clouds, for example, this corresponds to a cloud thickness of about 500 ft or greater.[25]

1. clear atmosphere,

2. off-surface cloud or haze layer, fireball below it,

3. off-surface or on-surface cloud or haze layer,* fireball above it,

4. off-surface cloud or haze layer and off-surface or on-surface cloud or haze layer, fireball between them,

and in each case the surface albedo may be low (~0.15) or high (~0.75).** In reducing a complex situation to one of these cases, one should consider only the nearest approximately complete cloud or haze layer above the fireball and the nearest approximately complete cloud or haze layer below it. If the fireball is partly above and partly below a cloud or haze layer, the two parts of the fireball should be considered as separate thermal sources.

Configurations 1, 2 and 3 have already been treated above (configuration 1 in Sections 1 and 3, and configurations 2 and 3 in the present Section 4) for low surface albedo. For high surface albedo and configuration 1, 2 or 3 the T' as specified for the corresponding low-surface-albedo situation should be increased by a factor of 1.5.***

*Note that an on-surface cloud layer is a fog.

**Surface albedos "range from about 5 per cent for forests to 25 per cent for deserts; green fields, humid earth, etc., have intermediate values. Snow reflects 65 - 89 per cent, depending on its freshness."[26] An urban-area "surface" without snow cover should be assumed to have a low albedo (~ 0.15), while an urban-area "surface" with a snow cover should be assumed to have a high albedo (~0.75).

***For convenience the factor corresponding to the transmissivity increase arising from a surface of high albedo below the fireball and observation point is taken equal to that corresponding to the transmissivity increase from a cloud layer above the fireball and observation point. Actually, judging from Cantor's experimental data,[27] the effect of a surface of high albedo below the fireball and observation point may be somewhat less than that of a cloud layer above them.

For example, a value T' = 1.5 should be used for configuration 1 if the thermal source and the observation point are above a surface of high albedo, and a value T' = 2.25 should be used for configuration 2 if the thermal source and the observation point are between a cloud deck and a surface of high albedo.* For configuration 4 and either low or high surface albedo a T' of 1.5 times that of the corresponding case of configuration 3, i.e., the case of configuration 3 which has the same off-surface or on-surface cloud or haze layer below the fireball, should be used.

A summary of the values of T' appropriate for use with each of the four configurations for cases of low or high surface albedo is given in Table 5.

Table 5

Values of T' Appropriate for Use With the Configurations Enumerated in the Text

Configuration number	Surface albedo	T'
1	low	1
1	high	1.5
2	low	1.5
2	high	2.25
3	low	As given in Section 4.1
3	high	1.5 times T' for corresponding low-surface albedo case of config. 3
4	low	1.5 times T' for corresponding low-surface albedo case of config. 3
4	high	1.5 times T' for corresponding high-surface-albedo case of config. 3

*For optical thickness $\sigma D \gtrsim 1$ (or, using Eq. 15, Section 2, $D \gtrsim 0.5\ V$, the range of greatest interest for thermal effects), these values of T' are in reasonably good agreement with experimental results reported by Cantor.[27]

4.3 FACTORS FOR USE WHEN THE EFFECTIVE HEIGHT OF THE FIREBALL IS LESS THAN ONE-QUARTER MILE

Actually the factors given in 4.1 and 4.2 are applicable (in the respective situations described) regardless of the height of the fireball. However, for clarity it is here recalled that the basic situation considered in 2.2, in which the fireball was assumed to be at an effective height of less than one-quarter mile, was one in which the surface was of low albedo and the fireball was essentially immersed in a haze extending up from surface level. The principal variants from this basic situation (but with the effective height of the fireball remaining below 0.25 mile) are those corresponding to the addition of (1) a cloud layer above the fireball, or (2) a snow layer under the fireball, or (3) a cloud layer above and a snow layer under the fireball. For these variants the respective factors T' that should be used are (1) 1.5, (2) 1.5 and (3) 2.25.

SECTION 5

SUMMARY AND CONCLUSIONS

In the preceding Sections of this report directions are given for calculating the transmissivity of the atmosphere for thermal radiation from a nuclear weapon burst of any yield and height and for an inclusive list of sets of atmospheric and surface albedo conditions. The directions are relatively simple and assume the availability of only standard descriptive and quantitative information (e.g., cloud types, cloud base heights, surface visibility) that is ordinarily recorded at airport weather bureau stations.

For nuclear weapon bursts with effective fireball heights (for thermal radiation) of less than one-quarter mile the transmissivity of the atmosphere for the weapon thermal radiation is given in terms of a formula involving visibility and based on experiments carried out by the present author.

For nuclear weapon bursts with effective source heights (for thermal radiation) greater than or equal to one-quarter mile and an atmosphere that is free of clouds and characterized by a surface visibility of 12 miles, it is shown, by means of phenomenological arguments and checks against experimental results, that the transmissivity of the atmosphere for the weapon thermal radiation may be found (for a given burst-target geometry) by a calculation which assumes the radiation to behave as though it were all 0.65-μ radiation passing through an atmosphere everywhere two thirds as dense (optically) as Elterman's[1] "clear standard atmosphere" and were attenuated by "scattering out" only (without "buildup" or "scattering in"). Factors are then given for modifying the values calculated for this special atmosphere to correspond to other situations, such as atmospheres containing cloud cover or haze (factors of from 0.1 to 1.5), and for taking into account high surface albedo (factor of 1.5). The factors for taking account of a cloud layer above the fireball (factor of 1.5) or a high surface albedo (factor of 1.5) or both (factor of 2.25) are found to apply also to situations in which the effective fireball height is less than one-quarter mile.

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13 ABSTRACT

The transmissivity of the atmosphere is estimated for thermal radiation from a nuclear weapon of any given yield and height of burst under various atmospheric conditions. Situations in which the effective source height (for thermal radiation) is less than one-quarter mile*, the atmosphere is unclouded and the surface of the earth (or its covering) is of low albedo are considered first. The transmissivity for these situations is given in terms of a formula derived from earlier experiments of the author. Situations in which the effective source height (for thermal radiation) is equal to or greater than one-quarter mile are then considered, and basic transmissivity values are given in terms of effective fireball height and zenith angle for the case of an unclouded atmosphere, a visibility of about 12 miles and a low surface albedo. Factors are then given for modifying the basic transmissivity values to apply to other situations, such as ones with cloud cover or haze, and for taking into account high surface albedo. The factors for taking account of a cloud layer above the fireball and/or a high surface albedo are found to apply also to situations in which the effective fireball height is less than one-quarter mile.

*The "miles" used in this report are statute miles.

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14. KEY WORDS	LINK A		LINK B		LINK C	
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T. J. Mathews
T. J. MATHWES
By direction

USNRDL-TR-1060

TRANSMISSIVITY OF THE ATMOSPHERE FOR THERMAL RADIATION FROM NUCLEAR WEAPONS

Mathew G. Gibbons

SPECIAL OCD SUMMARY

<u>The Problem</u>

Assessment of the thermal and fire effects of a given nuclear weapon burst on a given target requires a knowledge of the amounts of thermal radiation delivered from the nuclear weapon fireball to various portions of the target.. This in turn requires a knowledge of the transmissivity of the atmosphere for fireball thermal radiation.

<u>The Findings</u>

The transmissivity of the atmosphere is estimated for thermal radiation from a nuclear weapon burst of any yield and height and for an inclusive list of sets of atmospheric and surface-albedo conditions. Directions are given for choosing the one of these sets of atmospheric and surface-albedo conditions that most nearly corresponds to any actually specified set of such conditions.

For nuclear weapon bursts with effective fireball heights (for thermal radiation) of less than one-quarter mile the transmissivity of the atmosphere for the weapon thermal radiation is given in terms of a formula involving visibility and based on experiments carried out by the present author.

For nuclear weapon bursts with effective source heights (for thermal radiation) greater than or equal to one-quarter mile and an atmosphere that is free of clouds and characterized by a surface visibility of 12 miles, it is shown, by means of phenomenological arguments and checks against experimental results, that the transmissivity of the atmosphere for the weapon thermal radiation may be found (for a given burst-target geometry) by a calculation which assumes the radiation to behave as though it were all 0.65-μ radiation passing through an atmosphere everywhere two thirds as dense (optically) as Elterman's "clear standard atmosphere" and were attenuated by "scattering out" only (without "buildup" or "scattering in"). Factors are then given for modifying the values calculated for this special atmosphere to correspond to other situations, such as atmospheres containing cloud cover or haze (factors of from 0.1 to 1.5), and for taking into account high surface albedo (factor of 1.5). The factors for taking account of a cloud layer above the fireball (factor of 1.5) or a high surface albedo (factor of 1.5) or both (factor of 2.25) are found to apply also to situations in which the effective fireball height is less than one-quarter mile.

U. S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
San Francisco, California 94135

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1. Recipients of subject report are requested to make a correction in Equation 5 on page 5. The expression "$1.4\ S_T/V$" should be replaced by "$1 + 1.4\ S_T/V$."

E. R. Bowman
E. R. BOWMAN
By direction